

DEVELOPMENT OF WALKING MACHINES; HISTORICAL PERSPECTIVE

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ABSTRACT - The paper discusses the early history of machines and mechanisms related to the design of walking machines. Selected facts concerning the theory and the first ideas of mechanisms later used in the design of walking machines are presented.

KEYWORDS: History of Walking Machines, Mechanism Design

INTRODUCTION: FIRST WALKING MACHINES

From the ancient times people have been fascinated by legged locomotion. This fascination was reflected in mythology. According to the books of Iliad, written by Homer (VIII c. BC), one of the Greek gods built different walking devices. Some of them were human-like. In the old scripts from India we can find descriptions of mechanical elephants. In Egyptian pyramids archaeologists identified a wooden dog (toy) dated from the XX c. BC (Wolovich W.A. (1987)). Mimicking human or animal motion started with the decoration of water organs and water clocks with moving figures. The precursor of this type of devices was Ctesibius, who worked in Alexandria circa 270 BC. His student, Philo of Byzantium, wrote (circa 200 BC) the Mechanical Collection in which he described his teacher's inventions. The continuation of these works can be found in Hero's of Alexandra (I century AD): Treatise on hydraulics, Treatise on pneumatics, and Treatise on mechanics. He can be named the precursor of entertainment robots, due to his theaters with moving figures (Rosheim M.E. (1994)).

In the III c. AD in Sichuan province (China) a wooden walking machine Mu Niu Lu Ma was built under the supervision of a Chinese officer Zhu Ge-Liang (Shaoping Bai (2000); Yan H-S. (1999)). Mu Nu Liu Ma was used as a wheelbarrow for transportation of food supplies needed by the army. The machine was able to cover a distance of 10km in a day in an undulating terrain carrying a load of 200-250kG. (in Chinese MU means wooden, MA means horse, NIU means cow, in free translation it is *device powerful as horse and fast as cow*) was designed under the supervision of a Chinese officer Zhu Ge-Liang in the frame of preparation for the war against Wei kingdom located in central part of current China. Mu Nu Liu Ma was used as a wheelbarrow for transportation of food supplies needed by the army. The machine was able to cover a distance of 10km in a day in an undulating

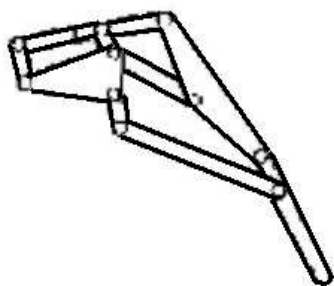


Figure 1: *Model of the leg build of 10 links*

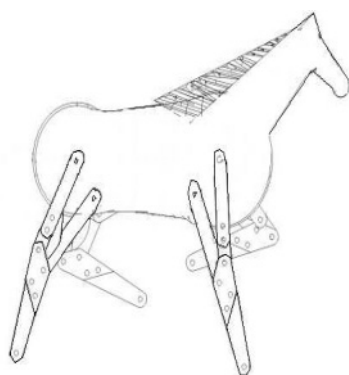


Figure 2: *Scheme of running wooden horse*

terrain carrying a load of 200-250kG. This story was recorded but no one of the authors gave an information about the design details. Probably, thanks to the complex mechanism incorporating wooden gears, the machine - when pushed - transferred its legs in a sequence similar to that of a cow or a horse when moving slowly. This story fascinated many researchers interested in walking machines who tried to reconstruct the device. Reconstruction done by Wan Jian from Xinjiang Institute of Technology (XX c) is one of the most well known. Works on Mu Niu Liu Ma copies were also taken in Taiwan. The investigations resulted in several prototypes resembling by view the horses or cows.

The Wang Jian prototype is probably the most complex one, each leg consist of 10 links – Fig. 1. After work of Wang Jian, Chiu-Chengping from Taiwan elaborated proposition of Mu Niu Liu Ma with similar leg structure. Fig. 2 illustrates the legs positions during motion of proposed mechanism. The size and proportions of the mechanical components is chosen on this way that the leg-end trajectories are similar to the trajectories observed during walk of animals – Fig. 3. There are also models with simpler leg structures. For example Chen-Paihung suggested the leg design with 4 links (Fig. 4). Models build by Shen-Huanwen and Kwang-Kai (Fig. 5) uses similar idea. In Mu Niu Liu Ma reconstructions the key question is how worked the mechanism powering the sequence of legs motion. This problem was studied by Wang Jian and others. In several models the proper leg movement was obtained by careful choice of lengths of leg links and the special design of mechanical connections between them.

Thanks to the complex mechanism incorporating wooden gears, the machine - when pushed - transferred its legs in a sequence similar to that of a cow or a horse when moving slowly. The detailed design (size of the mechanical components, the assembly details) is not know. This story was recorded but no one of the authors gave an information about the design details. Probably, thanks to the complex

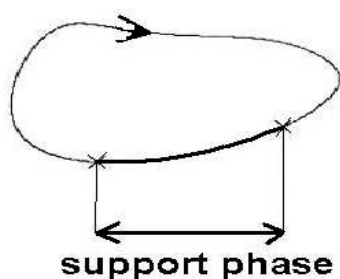


Figure 3: *Leg-end trajectory*

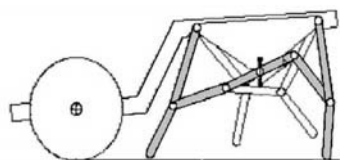


Figure 4: *Scheme of the design with 4-link legs (Chen-Paihung)*

mechanism incorporating wooden gears, the machine - when pushed - transferred its legs in a sequence similar to that of a cow or a horse when moving slowly. This story fascinated many researchers interested in walking machines who tried to reconstruct the device. Reconstruction done by Wan Jian from Xinjiang Institute of Technology (XX c) is one of the most well known. Works on Mu Niu Liu Ma copies were also taken in Taiwan. The investigations resulted in several prototypes resembling by view the horses or cows (Fig. 1).

In the XII century AD Badi'as- Zaman Isma'il bin ar-Razzaz al-Jazari designed a figure which upon manual emptying of a water basin automatically filled it again with water (Rosheim M.E. (1994)). He also described in his book many other devices, some of his own devise. In those gadgets actuation was due to the force of gravity transferred by levers or hydraulics to the limbs of figures. Leonardo da Vinci (1452-1519) used spring mechanisms as actuators in his ingenious machines. In the XVI and XVII c., as the precision mechanics capabilities improved, dolls dancing and/or playing diverse musical instruments were designed by many watch-makers (e.g. Juanelo Torrealano, Tukob Bullman, Christof Margraf). As we move through the ages towards the more recent times examples of toys or machines with manipulation or locomotion abilities become more abundant. Frequently the propulsion of the machine was produced by the motion of the wheels and not legs, but an outward appearance of the motion resembled walking.

An excellent example of mechanical dolls are the mechanisms built in the XVIII c. by Swiss watch-makers: Pierre Jaquet-Droz, Jean Frederic Leschat, Henri Jaquet-Droz and Henri Millardet (Chronicle (1992); Rosheim M.E. (1994)). Those dolls were programmable by exchange of pegs pushing cams. The dolls were capable of drawing and writing. As they were programmed, what was written or drawn could be changed. Very complex gears, cams and levers inside their bodies were powered by spring mechanisms. Droz brothers miniaturized the mechanical components

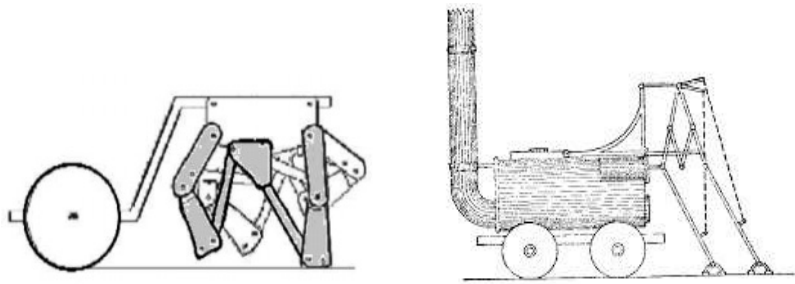


Figure 5: *Another version of Mu Niu Liu Ma (according to Shen-Huanwen and Kwang-Kai)*

Figure 6: *Steam engine with legs*

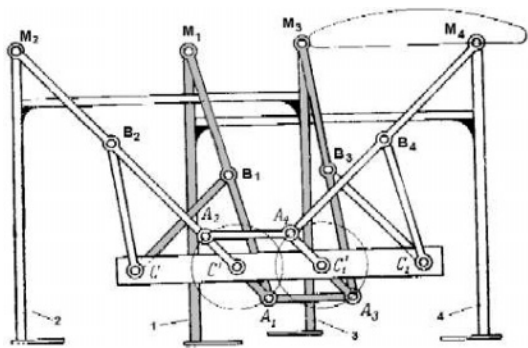


Figure 7: *Drawing of feet-walking machine; copy from Tchebychev works*

(Fig. 8). In their dolls they often applied mechanism transferring the motion by chains and teeth wheels. Until now this mechanism in large size, was used in milling machines, steam engines and wall clocks

In Japan (XVII-XIX c.) the famous Karakuri wooden dolls were produced in a significant number. The height of those devices was 35 cm. They were propelled by spring mechanisms built using whale bones. The doll was capable of moving forward holding a tea-cup. Once the cup was removed the doll stopped. Upon replacing the cup the doll turned around and moved away. Shoji Tatsukawa, using the design manual Karakurizui written by Yorinao Hosokawa in 1796, re-constructed such a doll (Rosheim M.E. (1994)). In the design of bigger machines, elaborated from the XVII till the XIX century, legs were used as prerequisite for propulsion. In 1814 Levis Gompertz proposed a "square wheel" consisting of 4 feet attached around a square frame capable of motion without inducing the vertical

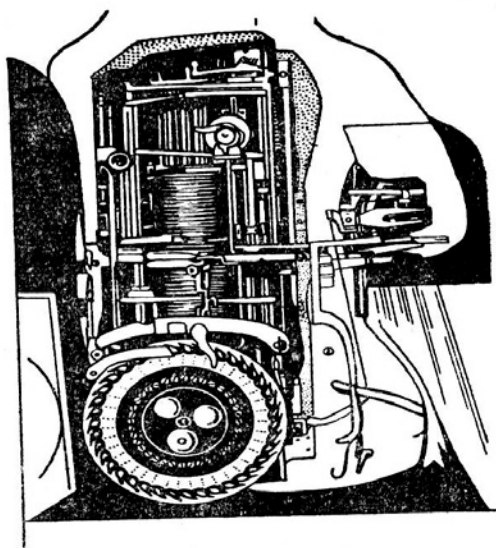


Figure 8: „Writer” designed by Droz brothers: view of the mechanizm (Milonov Ju.K. (1936))

oscillation of the axis. This idea was later modified and used in Pedrail - many feet attached around a frame. The device was used in a tractor for motion over soft terrain (Thring M.W. (1976)). In such a case feet are superior to wheels as they do not compress the soil in the direction of tractor's motion, thus reduce considerably resistance to motion. An excellent example of a vehicle supported by wheels, but powered by legs, is the so called Blueprint vehicle (XVIIIc.) (the name of the designer is not known) (Berns K. (2002)). In the early steam engine vehicles it was difficult to initiate the motion due to low friction between the wheels and rails (at that time the friction phenomena were not well identified). To overcome the problem with accelerating, extra legs were added to push or stop the vehicle. The devices designed at the break of the XVIII and XIX c. by Branton (Milonov Ju.K. (1936)) (Fig. 6) are examples of such steam vehicles. In 1893 L.A.Rygg patented the design details of the Mechanical Horse (Shin-Min Song and Waldron K.J. (1989)). In the same year G.Moore introduced the idea of The Steam Man (Thring M.W. (1976)). In the years 1821-1894 P.L.Tchebychev elaborated the design details of Stopochodjaszczaja Machina (Feet Walking Machine, Tchebychev P.L. (1955)) which similarly to the Chinese Mu Nu Liu Ma, when pushed transferred the legs in the same sequence as a horse or a cow. P.L.Tchebychev used parallelograms in his design. He underscored that the leg- end trajectories produced by his machine in relation to its body are similar to those of animals. XX c. was marked by an extensive development of diverse walking machines, especially past the fifties when first computer controlled machines appeared. As the resent

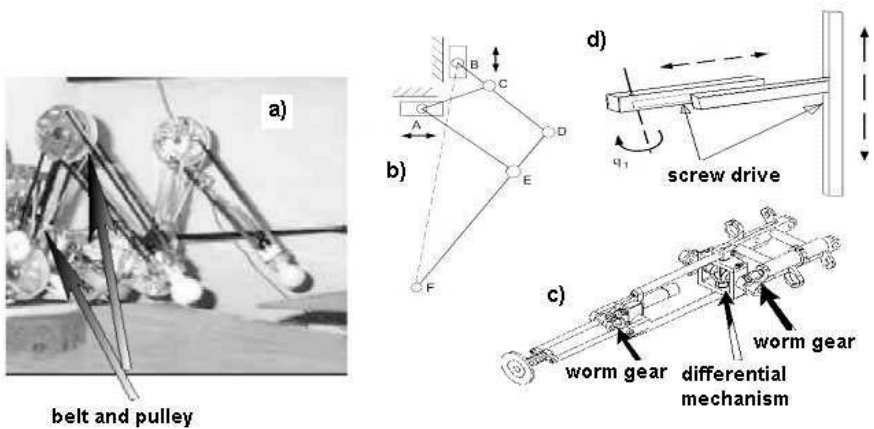


Figure 9: *Walking machine leg structures (with the data from Berns K. (2002))*: a) leg with a belt and pulley (picture of LAURON I, b) a pantograph leg (e.g. ASV), c) a differential mechanism placed in the hip joint (e.g. LAVA), d) a screw drive in a leg (e.g. MELWALK)

history of walking machines is very rich and is well described in several books (e.g. Shin-Min Song and Waldron K.J. (1989); Todd D.J. (1985)) or web pages (Berns K. (2002)) we shall not include it in this paper.

SHORT HISTORICAL OVERVIEW OF MECHANISM AND MACHINES USED IN WALKING MACHINES

The further text is an attempt to relate the currently used design solutions, utilised in walking machine legs, to the history of development of mechanisms. Fig. 9 presents the most frequently used leg structures applied in multi-legged machines. Usually revolute connections of many bars are used (Shin-Min Song and Waldron K.J. (1989)), e.g. the four-bar linkage presented in Fig. 10. Pantographs are also popular. Motion transfer is realised by: belts and pulleys, worm gears or differential gears. In conjunction with electric motors toothed-wheel gears are used for the reduction of angular velocity and to increase the torque.

If linear motion is desired screw and nut mechanisms are employed. The design of ankle joints is usually based on spherical connections (Fig. 11) or Cardan universal joints (Berns K. (2002)). There are also ankle joints that use several plates with revolute joints (Fig. 12, Tsukagoshi B.H. et al. (1997)). Parallel linkage passive ankle systems (e.g. ASV, Shin-Min Song and Waldron K.J. (1989)), which are a modification of the solution used in drafting machines, are also used. Summarising, the list of basic mechanisms employed in walking machines includes: pulleys, belt drives, toothed wheel gears, worm gears, differential gears, pantographs, four-bar linkages, spherical joints and universal joints.

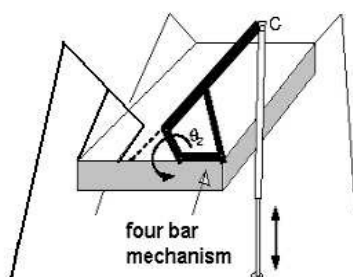


Figure 10: *Leg with a four bar mechanism*

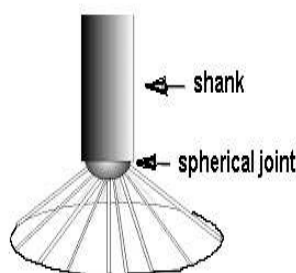


Figure 11: *Spherical connection in the design of walking machine ankle*

Now let us take a closer look at the history of their invention. Pulleys with ropes were used in antiquity. Herodotus (Vc. BC) mentions them in a passage of his Histories describing the construction of Egyptian pyramids (Fig. 13). Moreover, they are depicted in Assyrian reliefs (VIIIc. BC) (Kucharzewski F. (1924)). In the IVc. BC Aristotle mentions in his Problemata Mechanica "iron or metal wheels transferring motion to each other", what suggests that at his times simple gears were already known (Kucharzewski F. (1924), Fig. 14). On the sidelines, let us note that Problemata Mechanica is believed to be the first book mentioning mechanics in its title. A more detailed description of pulleys appears in the works of Archimedes (III century BC). He also developed the theory of compound pulleys - he constructed, among others, the polyspatos - a kind of a multiple pulley in which several ropes run in parallel over several rolls (Chronicle (1992)).

Belt drives were already known to the Chinese in the I c. BC. The proof of that can be found in Yang Xiong's The Dictionary of Dialects (15 BC) which describes the belt drives used in machines producing silk threads (Temple R. (1991)). Screws were known probably in Assyrian times. Certainly Archimedes (287-212 BC) employed them in his machines for launching ships. He used a system of pulleys and screws for that purpose. Unfortunately the blueprints of this mechanism have not survived till our times.

Detailed descriptions of mechanisms with toothed wheels (gears) are presented in Hero's On Lifting Loads (Ic. AD) (Kucharzewski F. (1924), Fig 15). This work also describes screws as wedges wound around cylinders. Moreover, he underscores that the action of a screw is obtained by its rotation and not by hammering as is the case with wedges. Hero also describes how with the help of a screw and a toothed wheel fixed to a shaft a considerable load can be moved. This brings to our mind a worm gear, in which a crank turning a screw imparts motion to a toothed wheel. Hero's writings also contain the description of a pantograph used

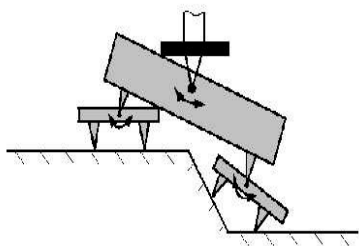


Figure 12: *Walking machine foot: plates with revolute joints*

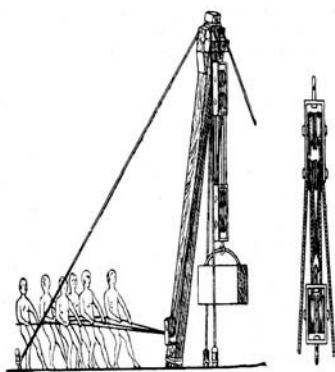


Figure 13: *Egyptian crane (Milonov Ju.K. (1936))*

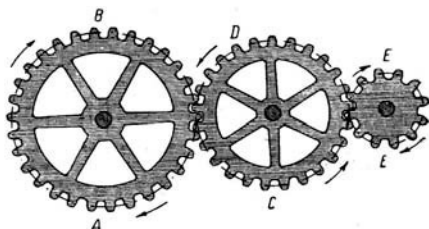


Figure 14: *Transfer of motion by the system of teeth wheels (according to Aristotle description, Milonov Ju.K. (1936))*

for copying drawings. It should be noted that Hero of Alexandria is treated as the first engineer, because he was the first to document his machines with detailed drawings. His drawings are very precise, convincing us that the machines really existed. Until his times the descriptions of mechanisms had been very general, thus imprecise, and the habit of illustrating them had not existed.

In Europe Philo of Byzantium (260-180 BC) described something that he called a cross joint (Chronicle (1992)), i.e. a Cardan universal joint. This type of mechanism was used in China in the II century BC in lamp holders (Temple R. (1991), Fig. 16). The earliest Chinese reference to this mechanism is made in the Poem About Beautiful Ladies composed about 140 BC by Sim Xiangru. The Cardan universal joint got its name from Girolamo Cardano (1501-1576), who personally did not claim that he invented it, but described it in detail in his work *De Subtilitate* (1550). Differential gear was used in China in the II century AD in the so called carts pointing south. A nephrite figure regardless of the trajectory of motion of the cart always pointed its finger to the south. This was possible due to the system of gears containing a differential gear connected to the wheels of the

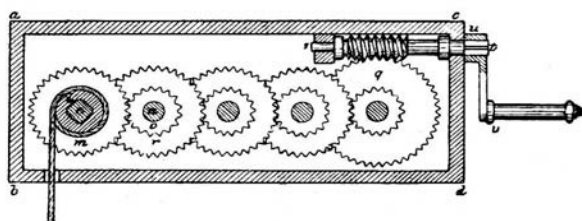


Figure 15: *Mechanism designed for lifting the loads (reconstruction according to Heron works, Milonov Ju.K. (1936))*

cart. It is probable that this type of gear existed earlier. According to a chronicle, dated 500 AD, the south pointing cart was built on emperor Zhou's order (beginning of the first millennium BC), to enable a legation to return home in low visibility. Fully confirmed is the information that differential gears existed in 80 BC in Greece (Temple R. (1991)). Many works of ancient authors have been forgotten. After stagnation in the middle ages, progress in mechanics was marked by Leonardo da Vinci (1452-1519), who reinvented the worm gear, and described the universal joint. He experimented with many motion transmission mechanisms (Kucharzewski F. (1924), Fig. 17). He also noted that every motion is subjected to resistance, thus he concluded that to sustain motion an engine is needed. It is difficult to ascertain when exactly did multi-link devices with planar revolute joints appear. Nevertheless, it is pretty certain that they were used in conjunction with levers in the times that pyramids were constructed, because texts mentioning such devices exist (e.g. Herodotus in Vc. BC wrote about such mechanisms). According to the blueprints of the already mentioned Chinese machine they existed in the IIIc. AD. It is difficult to ascertain when the spherical joint appeared. The above brief overview shows that many simple mechanisms that are currently used in walking machines appeared in antiquity. Neglecting the problem of actuation, the modern designs of walking machines could have appeared over a thousand years ago. However the lack of appropriate motors hindered the development of walking machines.

Up till the XIX c. mechanisms had been designed on the basis of a flash of genius and the experience gained by trial and error. This was due to the lack of an adequate theory. The development of such a theory was impeded by the prevailing misconception established by Aristotle (384-322 BC) that the natural state of a body is its immobility and thus bodies remain motionless or try to attain that state by themselves (due to natural motion). Otherwise for a body to move a force has to be applied to it (causing unnatural motion). Only in the XIV century this claim was disputed. It was Galileo Galilei (1564- 1642) in his *Dialogue Concerning the Two Chief Systems of the World - Ptolemaic and Copernican*, published in 1632, who finally asserted that for a body to move with a constant velocity no force is required, thus he laid down the foundation for the formulation of the principle of inertia. He claimed that the state of rest is indistinguishable from the state

of uniform motion in a straight line, hence formulated the principle of relativity. The investigations of motion were inseparable from astronomy. Initially scientists aspired just to describe the motion of planets without studying the reason for their behaviour. Nicolas Copernicus (1473-1543) postulated the heliocentric system, which was a geometrical construction considerably simplifying the description of the motion of planets in comparison with Claudius Ptolemy's (II AD) epicycles specific to the geocentric system. Later Johannes Kepler (1571-1630), using detailed astronomical data collected by Tycho Brahe (1546-1601), improved the Copernican model and developed his laws of motions of planets, in which he postulated elliptic trajectories - still geometrical concepts. Rene Descartes (1596-1650) showed the relationship between geometry and algebra by creating analytic geometry, hence reducing geometrical considerations to the manipulation of algebraic equations. Galileo established the relationship between: time, velocity and distance travelled by a body in a uniformly accelerated motion. The considerations of astronomers and Descartes treated trajectories as static entities - imaginary static traces left by moving bodies. It was Isaac Newton (1643-1727) who combined Galileo's kinematic considerations with geometrical models produced by astronomers and through the introduction of the method of fluxions (differential calculus) and by postulating gravitational force formulated his three laws of motion and the law of gravitation. Those were contained in *Philosophiæ Naturalis Principia Mathematica* published in 1687. This book is the foundation of mechanics, i.e. the science investigating the interactions of bodies through forces. It combines both dynamics (theory of causes of motion) and kinematics (theory of the process and effects of motion). But it was due to Gottfried Wilhelm Leibniz (1646-1716), the independent co-inventor of the differential calculus, that this calculus received its current notation. It must be mentioned that in 1675 G.W. Leibniz constructed a computing machine (Fig. 18). The first such devices appeared earlier, in break of XVI and XVIIc., but Leibniz machine was the most complex and minaturized, mechanical structures utilized there were later applied in first commercially available mechanical computing machines (from 1878) (Milonov Ju.K. (1936)). Leonhard Euler (1707-1783) combined Newton's method of fluxions and Leibniz's differential calculus into mathematical analysis and described it in *Mechanica* (1736). He formulated analytical mechanics in his *Theory of the Motions of Rigid Bodies* (1765). Later he formulated variational principles to determine the optimal ship design. Finally in *Theoria Motus Corporum Solidorum* (1765) he decomposed the motion of a solid into translational and rotational motion and introduced Euler angles. Meanwhile, in 1743, in *Traite de dynamique*, Jean Le Rond d'Alembert showed how to reduce a dynamics problem to a one of statics. To do this one has to balance all the external forces and a fictitious force equal to the force of inertia. In 1756 Joseph-Louis Lagrange (1736-1813) applied the calculus of variations to mechanics. His foundations of dynamics were based on the principle of least actions and on kinetic and potential energy. In 1788 he summarised in his *Mecanique Analytique* all the results obtained in mechanics since Newton. He introduced generalised coordinates and provided us with a method of generating second order differential equations of motion for a system with any number

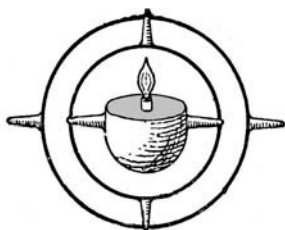


Figure 16: *Lamp holder*

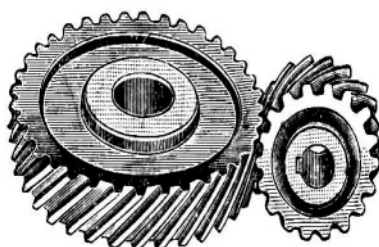


Figure 17: *Leonardo da Vinci worked on the gears improvement; he invented helical gears, Milonov Ju.K. (1936)*

of degrees of freedom. In 1843 William Rowan Hamilton (1805-1865) discovered quaternions. The works of Leonard Euler, Michael Chasles (1793-1880), stating that any motion of a rigid body can be reproduced by a single translation followed by a single rotation about some axis, culminated in the formulation of the theory of screws in 1876 by Robert Stawell Ball (1851-1913) (Duffy J. (1999)). All those mathematical developments were well suited to the description of motion of point masses or rigid bodies. With the emergence of a multitude of mechanisms in the early XIX century, spurred by the invention of the steam engine due to Thomas Newcomen (1663-1729) and its improvement by James Watt (1736-1819), mathematicians were faced with the problem of finding a framework for categorising them. Moreover, in the XIXc. scientists- engineers started to believe that machines should rather be designed using mathematical principles than by trail and error. In 1854 Pafnuty Lvovitch Tchebychev (1821-1894) published his *Theorie des mecanismes connus sous le nom de parallelograms* in which his polynomials appeared for the first time. He later studied mechanisms converting rotary into translational motion and even mechanical calculating machines. But it was Franz Reuleaux (1829- 1905) who classified mechanisms on the basis of how they constrained motion. He created a library of mechanisms that could be combined to create complex machines. In 1864 he came upon the idea to describe machines as kinematic chains linked by pairs of geometric constraints (Moon F.C. and F. Reuleaux (2000)), thus inventing the notion of a kinematic pair. Towards the end of the XIX c. many scientists concentrated on the theoretical aspects of kinematics, e.g. in 1892 Lorenzo Allievi (1856-1941), Ceccarelli M. (1999) wrote *Kinematics of Planar Couplers*, in which he summarized the knowledge about planar mechanisms that had been accumulated until his times and proposed a classification of

elementary mechanisms. Due to complex kinematic structures, difficult dynamics and problems with the generation of stable gaits of walking machines, control of those devices is of paramount importance. As friction hinders the transmission of motion in complex mechanisms the problem of their actuation becomes vital. Only at the turn of the XVIII c. steam engines or clockwork mechanisms were proposed as a means of propulsion in walking machines (e.g. in the Mechanical Horse). It cannot be denied that the current intensive development of walking machines should be attributed to two factors: firstly, the invention of an electric motor, and secondly, the rapid development of control systems sustained by the ever increasing computational power and miniaturisation of computers. This brings us to the XIX c. In 1829 Michael Faraday (1791-1867) elaborated the idea of a motor which consisted of a static magnet and a conductor rotating around it. This led M.H.Jacobi (1801-1874) to build in 1834 the first electric motor capable of doing useful work. The advent of miniaturised digital computers, in the later half of the XX c. enabled the creation of walking machines. The influence of the developments in the fields of electronics and computer science on the design of walking machines cannot be overestimated. The history of electronics and computers in particular is well documented, e.g. Ligonnierre R. (1987). Nevertheless, for the sake of completeness, a few milestones have to be included in this overview. Both the evolution of technology (hardware) and mathematical foundations were important. The former is marked by the invention of the transistor in 1946 in Bell Telephone Laboratories by John Bardeen (1908-1991) and Walter Brattain (1902-1987) supplemented by the theory of p-n junctions and the theory of transistor operation formulated (1948) by William Shockley (1910-1989). This led in 1958 to the design of the first integrated circuit by J.S. Kilby (b.1923) from Texas Instruments. At that time Robert Noyce (1927-1990) invented the diffusion method of connecting electronic elements (Temple R. (1991)). The introduction of the so called planar technology in 1961 by Fairchild Semiconductors enabled the mass production of integrated circuits. Finally, in 1972 Intel Corporation introduced to the market its first microprocessor - the 4-bit Intel 4004, substituted by the 8-bit Intel 8008 in 1972, and the famous 8-bit Intel 8080 in 1974. By no means this summarises all important technological developments, but the bounds imposed on conference papers require brevity. The technological developments have been paralleled by the evolution of the theory of computations. Again, only just a few milestones can be cited. Gottfried Wilhelm Leibniz in the years 1679-1702 worked on the binary representation of numbers.

The foundations for the formal logic were laid down by the seminal publications of Augustus de Morgan (1806-1871) in 1847 and 1860, and George Boole (1815-1864) in 1847 and 1854 (O'Connor J.J. and Robertson E.F. (2003)). In 1937 Allan Turing (1912-1954) working on the theory of computability defined an abstract machine (Turing machine) containing a finite state control automaton and an infinite length tape divided into cells which can hold symbols. This abstract machine was later instrumental in the classification of formal languages (Noam Chomsky, b.1928) and thus the development of high level computer programming languages. In 1938 Claud Shannon (1916-2001) in his Ph.D. thesis showed how to use the binary

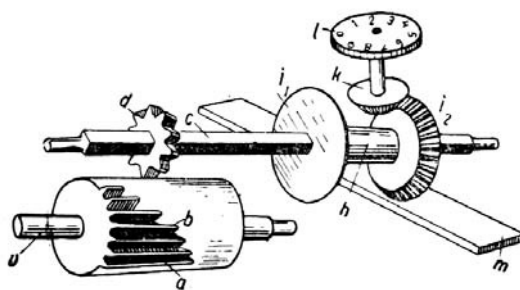


Figure 18: *Structure of Leibniz computing machine, Milonov Ju.K. (1936)*

number system and relays to construct arithmometers. In 1945 John von Neumann (1903-1957) pointed out that there is no contradiction between the representation of data and programs operating on that data, thus both can be stored in the same memory. This led to the design of computer architectures with programs and data residing in the same memory, i.e. the vast majority of modern computers. All the above developments led to the present state of walking machine design. It is anticipated that towards the middle of the XXI century we shall be able to design biped running robots capable of outperforming human soccer players (Burkhard H.D. et al. (2002)).

CONCLUSIONS

The study of the history of engineering developments is by no means an easy task, especially its early stages, as diverse sources quote different chronology. In the above overview we tried to verify the dates in several sources (not all cited). We believe that the knowledge of history besides enriching can also influence the design of modern machines by reminding of certain solutions. Before the II World War at Warsaw University of Technology the history of mechanics was lectured to the students as a separate subject. The lecture dealt not only with historical facts but also with the design of simple mechanisms and the evolution of theoretical knowledge associated with mechanics. This led to a better understanding of the subject, because the students learned how modern designs have been arrived at. Mechanics was presented as an evolution of engineering thought and not as a set of disjoint modern solutions. The reintroduction of such lectures should be reconsidered once again.

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